"Machine Detection of Operationally Significant Cognitive Events for C4ISR"

2003June22

Sponsored by

Defense Advanced Research Projects Agency (DOD)
(Controlling DARPA Office)

ARPA Order K475/71

Issued by U.S. Army Aviation and Missile Command Under

Contract No. DAAH01-03-R058

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Effective Date of Contract:
Start: 22-10-02
Contract Expiration Date:
End: 22-06-03
Reporting Period:
01-05-03 to 22-06-03

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Date   _____22-06-03_____

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REPORT DOCUMENTATION PAGE

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1. REPORT DATE (DD-MM-YYYY) 22-06-2003	2. REPORT TYPE Final Technical Report	3. DATES COVERED (From - To) 01-05-2003 – 22-06-2003

4. TITLE AND SUBTITLE	5a. CONTRACT NUMBER
Machine Detection of Operationally Significant Cognitive Events for C4ISR	DAAH01-03-CR058
	5b. GRANT NUMBER
	5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)	5d. PROJECT NUMBER
Lankford, Christopher P.	
	5e. TASK NUMBER
	5f. WORK UNIT NUMBER 0001AB

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)	8. PERFORMING ORGANIZATION REPORT NUMBER
ERICA Inc. 100 2nd St. NW Charlottesville VA 22902	ECR0002Z

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)	10. SPONSOR/MONITOR'S ACRONYM(S)
U.S. Army Aviation and Missile Command ATTN: AMSAM-RD-WS-DP-SB (Horton Nuckols, P.E.) Bldg 7804 Room 204 Redstone Arsenal AL 35898	
	11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT

Approved for public release; distribution unlimited.

13. SUPPLEMENTARY NOTES

14. ABSTRACT

A machine capable of detecting cognitively significant events in its user could prevent potential disaster by signaling to commanders that a soldier is under high stress. This project seeks to establish that these cognitive events can be captured in an autonomous fashion through the use of an eye-tracking system. The experiment in this study requires subjects to find a particular person hidden in a sequence of complex images that contain crowded scenes of different people performing different activities. Project tasks included creating the test stimulus, running test subjects, and analyzing the captured data. This analysis indicates that a pupil dilation increase during a period of prolonged fixation occurs when the test subject finds the target person in the stimulus. Additional testing is necessary to validate this finding in a more realistic setting, but this study represents a preliminary step in developing a machine capable of autonomously detecting cognitive events.

15. SUBJECT TERMS

Pupillometry, Eye-tracking, Human Computer Interface, Cognitive Monitoring, Autonomic Observables of Cognition

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON Chris Lankford
a. REPORT UNCLASSIFIED	b. ABSTRACT UNCLASSIFIED	c. THIS PAGE UNCLASSIFIED	SAR	17	19b. TELEPHONE NUMBER (include area code) 434-296-3846

Table of Contents

Table of Figures

Summary

Failure of military personnel to report their status to their commanders may result in catastrophe for both the soldiers and their units. A machine capable of detecting cognitively significant events in its user could prevent potential disaster by signaling to commanders that a soldier is under high stress. This project seeks to establish that cognitive events can be captured in an autonomous fashion through the use of an eye-tracking system. To demonstrate feasibility, a laboratory experiment was conducted. The experiment required subjects to find a particular person hidden in a sequence of complex images that contain crowded scenes of different people performing different activities. Project tasks included creating the test stimulus, running test subjects, and analyzing the captured data. This analysis indicates that a pupil dilation increase during a period of prolonged fixation occurs when the test subject finds the target person in the stimulus. Additional testing is necessary to validate this finding in a more realistic setting, but this study represents a preliminary step in developing a machine capable of autonomously detecting cognitive events.

Introduction

The interface between human and machine has classically been one-sided. Humans command machines with little assistance offered by the machine besides feedback regarding current status of the command execution. The machine has been little more than a workhorse, a method for accomplishing work faster and more efficiently. Over the past decade, the idea of ubiquitous computing has arisen. Under ubiquitous computing, machines permeate society, and the interaction between human and machine becomes more collaborative and hidden in nature. Machines augment how humans perform their work and live their everyday lives, but the physical presence of the machines is not felt.

Computational power has been a major impediment to the proliferation of ubiquitous computing devices. Without significant processing capabilities, computers cannot have the eyes and ears they need to successfully partner with humans in a naturalistic manner. Fortunately, recent advances in both computing resources and analytical techniques now allow the first steps into a realistic investigation of pervasive computing techniques to occur.

Augmentative computing can be particularly helpful in areas where vigilance of a human operator is necessary for successful task completion. This is especially apparent in military applications where military personnel must report their status to their commanders. Failure to do so may be catastrophic for both the individual and his or her unit. A machine capable of detecting cognitively significant events would determine when military personnel are incapacitated or overloaded due to a high stress level associated with their duties. This would allow commanders to assess the status of all of their troops and to reallocate resources as needed. The machine could also reinforce the efforts of the human, possibly streaming additional data on its own that the human should be reporting. For example, consider an analyst that must recognize friendly versus hostile aircraft. If many aircraft on the screen appear, the analyst may be overloaded as he or she examines each aircraft and may not report his or her findings in

a timely manner. Machines capable of detecting when the operator recognizes an aircraft or when the operator is engaged in significant cognitive activity could signal the soldier's commander that recognized aircraft are present and intervention may be necessary. This has the potential to revolutionize combat and to assist America as it strives to maintain the superiority of its armed forces.

This project seeks to establish that these operationally significant cognitive events can be captured in an autonomous fashion through the use of an eye-tracking system. To demonstrate feasibility, a laboratory experiment was conducted. The following report describes the progress made in this experiment. The next section discusses the eye-gaze and analytical technology employed in the study. The Results and Discussion section presents the test stimuli used in the experiment and the findings based on the test subject data. The conclusion presents an interpretation of the data with recommendation for further work.

Methods, Assumptions, and Procedures

The Eye-gaze Response Interface Computer Aid (ERICA) is a unique device developed by Eye Response Technologies that determines where its user is looking on a computer display. ERICA currently serves two different functions [1]:

1. Providing individuals with disabilities, such as quadriplegics, with eye-driven computer control. The user's eye can type and control all of the mouse functions on a Windows based computer thereby enabling access to any Windows software.
2. Analyzing where people look as they view static images, video clips, or interact with software. These users include researchers, marketing firms, and software usability and design experts.

Professor Thomas Hutchinson conceived ERICA in 1983 while watching a television documentary about elephants. He noticed that the photographers used infrared light to photograph the elephants. Furthermore, he observed a relationship between the elephant's eye movements and the infrared picture. Hutchinson reasoned that a computer outfitted with an infrared camera could determine the gaze position of its user and then use that data to control the computer. Research focused on implementing the system was successful. [2] outlines the advantages of having an eye-controlled computer and describes the theory behind its operation.

The ERICA system relies on infrared light to determine a user's direction of gaze. An infrared light emitting diode (LED) resides at the center of a lens that is attached to a video camera feeding its signal to a computer. This LED bathes the user's face in infrared light at 880 nanometers, a wavelength of light invisible to humans. When the light from this LED strikes the eye, two features, the glint and the bright eye, appear in the camera image, as shown in Figure 1. The glint is the specular reflection of the LED from the front surface of the eye, which is the cornea. Essentially, a specular reflection is the intense reflection of light from a curved, shiny surface; therefore, the glint appears as a small, bright dot to the camera. The bright eye is formed by the absorption and reemission of the infrared light by the retina of the eye. To an infrared

sensitive camera, this makes the pupil glow, thereby discriminating it from the surrounding iris [1].

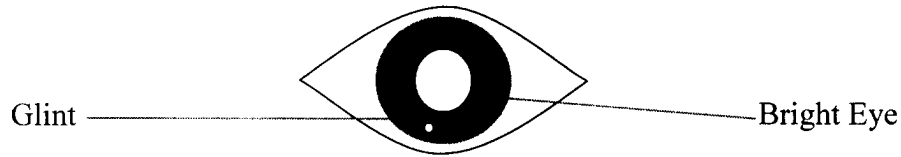Glint ——————————————————<——————————Bright Eye

Figure 1. Features formed when infrared light strikes the eye.

The ERICA system locates these two features of the camera image and determines where the user is looking based upon the vector distance between the two features, as shown in Figure 2 [1].

Directed at the camera   Directed above the camera

Directed up and to the right of the camera   Directed up and to the left of the camera
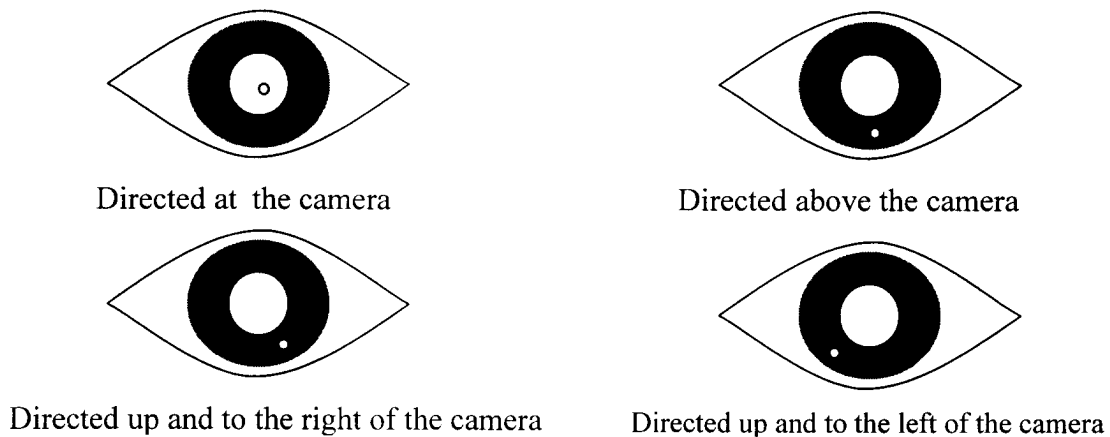
Figure 2. Glint and bright eye relationships.

In its nearly 20-year history, over 300 students have performed research with the device. ERICA developed the first eye-controlled computer for people with disabilities and has engaged in numerous research activities concerning the analysis of eye movement data. These activities include assessing novice/expert differences in tasks such a mammography screening, analyzing user interfaces, determining stress level and emotional response to stimuli, and detecting deception by test subjects, among many other areas [3-15]. Many experiments have shown that scan path and pupil dilation measures can indicate differing skill levels between subjects and show when subjects experience high levels of cognitive activity or stress [3-5, 8].

ERICA was originally created to assist people with disabilities by providing them with a means to communicate. As ERICA developed, another potential market for the system became apparent – the system could facilitate analysis of a user's eye movements as well as determine fluctuations in pupil dilation. Software needed to be developed to allow experimenters to construct experiments and to analyze the raw data stream of gaze positions and pupil dilations that ERICA emits 60 times a second. GazeTracker is the application that resulted from this development [16].

GazeTracker offers three modes - image analysis, video analysis, and software application analysis. GazeTracker's image analysis mode allows researchers to study how individuals react to still images shown on the computer display. It outputs fixation, scan path, and pupil dilation measures. Researchers can also identify regions of interest, called LookZones, that give more in-depth information on particular areas of the screen, such as percent time spent in the area or number of times the area was observed. GazeTracker's strength rests in its ability to facilitate analysis of the eye-tracking data. Figure 3 depicts GazeTracker superimposing a test subject's scan path, fixations, and LookZones on the stimulus. The size of the fixation reflects the fixation's duration. The fixations and scan path have adjustable transparency to enable viewing of the underlying content. Figure 4 shows GazeTracker's 3D Analysis method, which creates three-dimensional views of the stimulus based on time spent in the regions of interest.
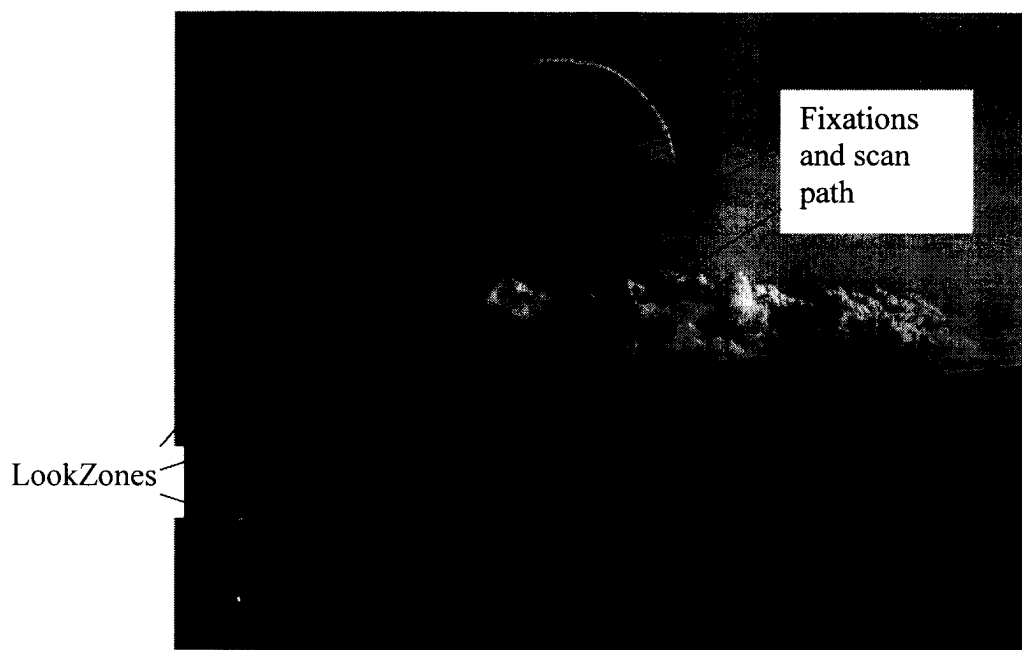

Figure 3. Image with scan paths, fixations, and LookZones.

Current Subject: Time in LookZones

1.45

30.30 %

Figure 4. Three-dimensional analysis of Figure 3.

A novel feature of the GazeTracker software is its ability to synchronize recording of eye-tracking data with computer state data from any Windows application. The gaze position on the computer display and pupil diameter of a user is recorded as they operate the computer. It records all keystrokes and mouse clicks and movements that the test subject performs while the analysis session is recording. While recording, both the eye-gaze system and the analysis software are running in the background of the computer, passively recording the actions of the user with little and generally unnoticed degradation in system performance.

GazeTracker's video analysis records how individuals react to video files shown on the computer. The software knows what frame of the video file is shown on the screen, so it can associate a recorded position of gaze to the frame shown. Furthermore, the LookZones may be specified to change size, shape, and position throughout the video. This allows a LookZone to be placed over a moving object, such as the aircraft in the AVI files described above, and the software would still provide accurate measures relating to the number of times the LookZone is observed, time spent in the LookZone, or pupil dilation while the zone is observed. This feature is a critical and unique component of the GazeTracker system and greatly simplifies analysis in the experiment described in the original proposal.

In the original experiment, the stimulus shown to each test subject was to be comprised of audio-video interleave (AVI) files. The system would measure the subject's eye response as they view each file. Each file would show vehicles navigating a scene.

However, after discussion with the technical monitor, Dr. Allan Steinhardt, the decision was made to employ sequences of images instead of AVI files. This would

simplify the experiment in an effort to uncover the basic impact of an image recognition effect on pupil diameter and fixations metrics.

The initial experiment was divided into two phases. The first phase tested object recognition, and the second phase tested person recognition. In each phase, the subject was presented with a random sequence of images. Each image was divided into nine blocks. Each block had a different graphic. Before each phase, the test subject was shown a graphic to recognize. During the experiment, whenever the test subject saw the graphic to be recognized, he or she pressed the spacebar. When they had finished examining all blocks in an image, they said, "Done," and the experimenter then instructed the GazeTracker software to present the next image by clicking the mouse button. Each image had between zero and nine graphics to be recognized. Each phase had twelve images. Thirty valid recognitions should have occurred in each phase. Sample images from the two phases are shown in Figure 5 and Figure 6. The tank graphic should be recognized in Phase I. The Saddam graphic should be recognized in Phase II.
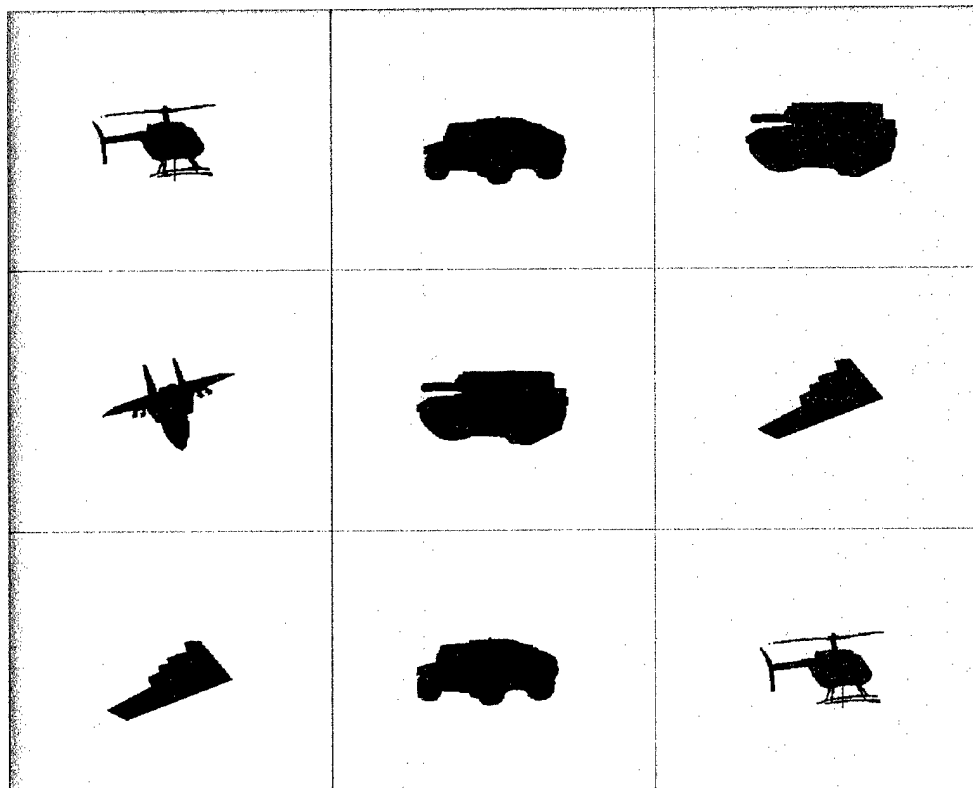

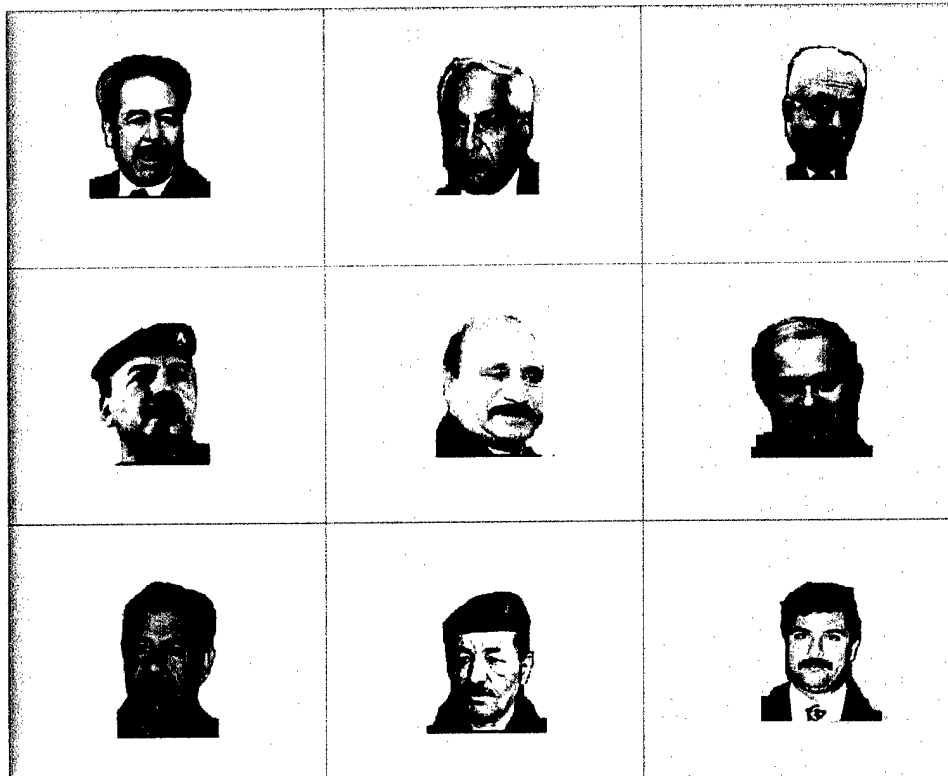Figure 5. Sample object recognition picture.

Figure 6. Sample face recognition picture.

After creating the stimulus, testing started. Eleven subjects were tested. Preliminary data analysis was conducted on these subjects.

This analysis focused on visually inspecting trends in pupil diameter. Trends seem to be apparent only on the first images observed in each phase for each subject. Specifically, the pupil diameter seems to decrease and then increase approximately one to two seconds after the image appeared. On the remaining images, pupil dilation does not seem to consistently change in such a significant manner. Interviews with the test subjects revealed that most subjects felt the test was easy after they had performed the task on the first image. They could even rely on peripheral vision to accomplish identification. This implies that the pupil dilation change is related more to concentration or mental workload effects than to recognition effects. Figure 7 and Figure 8 show example pupil graphs for a test subject observing the first images displayed in both phases.
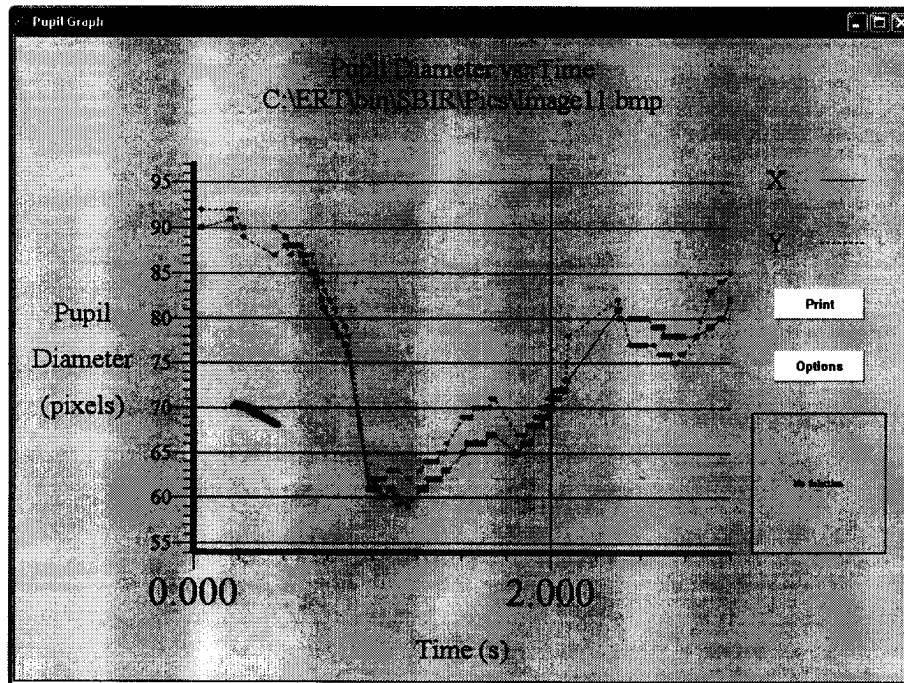
Figure 7. Sample object recognition phase pupil graph.
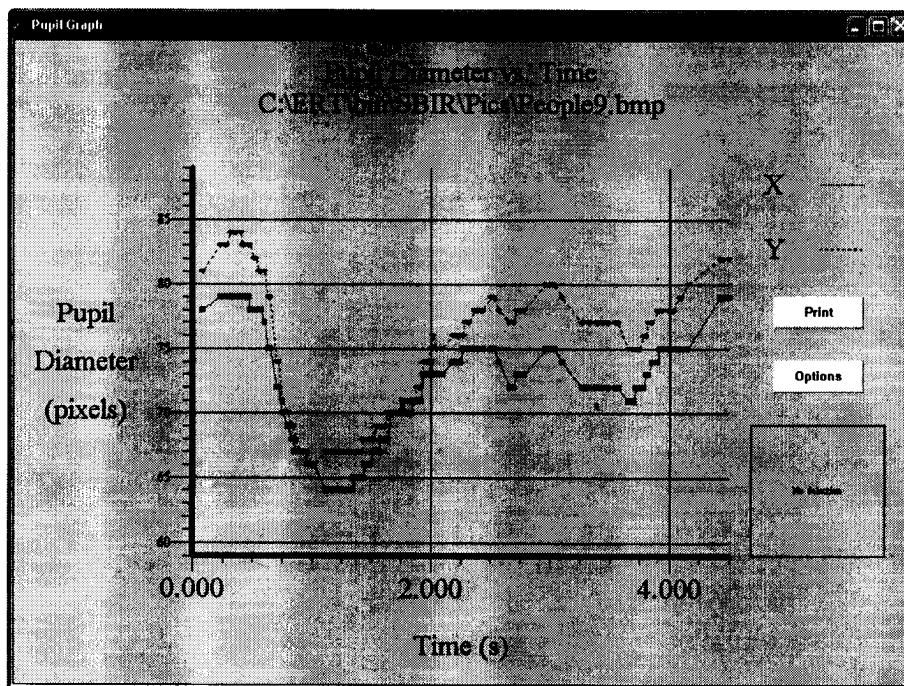
Figure 8. Sample face recognition phase pupil graph.

After presenting these preliminary results to Dr. Steinhardt, it was decided to include a more complex recognition task in the experiment. Different stimuli were then examined. Specifically, AVI files of crowd scenes, AVI files of shapes morphing from one design to another, and intelligence photographs from different US military actions were investigated. Each design was eliminated because of either difficulty in generating

an appropriate test stimulus (the AVI files) or due to specialized knowledge being needed by the test subjects (intelligence photographs). Consequently, the final experiment used pictures from the *Where's Waldo* series of children's books [17-18]. These books require its reader to examine an extremely detailed crowd scene of different people performing many different tasks. The goal is for the reader to find the Waldo character. Each scene contains many elements that resemble the Waldo character, but the Waldo character appears only once. Figure 9 and Figure 10 shows the Waldo character and a sample image. Six images from two different books were scanned into the computer and used in GazeTracker's Image Analysis mode. Each test subject observed an image until he or she found Waldo. The subject then pressed the spacebar on the keyboard, and the system advanced to the next image.

Figure 9. Waldo character [17].

Figure 10. Sample Waldo scene with Waldo circled (Waldo was not circled during the test) [17].

Results and Discussion

Ten subjects were tested in this study. Due to time constraints, rigorous statistical analysis of the collected data could not be performed; however, several general trends appeared that merit further investigation.

Analysis focused on images for which the test subjects exhibited difficulty in finding Waldo as reflected by the total time spent examining the image. Subject observation times were clustered below ten seconds and above fifteen seconds, so only images where subjects observed the picture for more than fifteen seconds were analyzed. Seven of the ten subjects observed one or more image for more than fifteen seconds. A total of eleven images were observed for more than fifteen seconds.

The primary finding of this study was that fixations with an increase in pupil dilation and a duration greater than fifty percent of the mean fixation duration occurred when a subject observed Waldo. The data showed other prolonged fixations and other increases in pupil dilation, but a prolonged fixation combined with an increase in pupil dilation did not occur unless the subject was observing Waldo. Figure 11 and Figure 12 show an example of this trend. The size of the fixation indicates its duration.

Figure 11. Scan path showing a Waldo search. Waldo is under Fixations 98 and 99 in the left image and 146 in the right.

Figure 12. Pupil dilation graphs for the Waldo search. Note the increase in pupil dilation at the end of the search when Waldo is found.

Figure 13 shows a subject who identified that he found Waldo; however, he did not find the true Waldo. As shown in Figure 13 and Figure 14, there is a large fixation at the incorrect Waldo, but there is not a corresponding increase in pupil dilation at the end of the search.

Figure 13. Scan path showing a subject mis-identifying Waldo (Fixation 59). The correct Waldo is circled red.

Figure 14. Pupil dilation graph for the above visual search. There is no increase in pupil dilation at the end of the search.

Conclusions

The trends described above appeared in the eleven images meeting the selection criteria for total search duration. This preliminary study shows promise in finding a metric that can indicate when image recognition occurs; however, several additional studies will be needed.

First, another study that requires the test subject to find two people in the image should be conducted. This would allow study into how the pupil changes after recognition occurs. Fortunately, the Waldo series of children's books have images where two people need to be found – a Wizard and Waldo. The same protocol described above could be used for these images. The subject would press the spacebar each time he or she finds the target, and the image would change after two key presses.

After conducting another study and finding if the same recognition effect holds, a real-time method to predict when Waldo was found with the collected data could be developed. The next study would not have the test subject signal when they had found Waldo; the image would automatically advance when the metrics related to Waldo recognition occurred.

Assuming the above tasks were successful, the metrics could then be studied in a real-world military situation, such as when intelligence analysts examine incoming image data and must make quick decisions concerning the nature of a possible threat. If the metrics apply to a real-world situation, this would allow a system to act as an assistant to an image analyst. When the analyst fails to consciously recognize an object, the system could signal to the analyst that they need to examine the object in more detail. This would be one of the first examples of a machine capable of autonomously detecting cognitive events.

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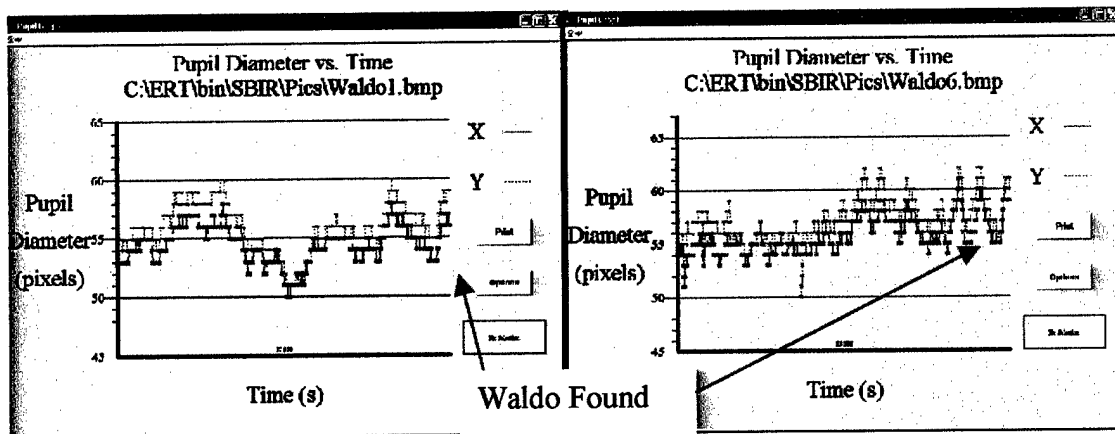[18] M Handford, *The Great Waldo Search*. Vicenza, Itealy: Little, Brown and Company, 1989.

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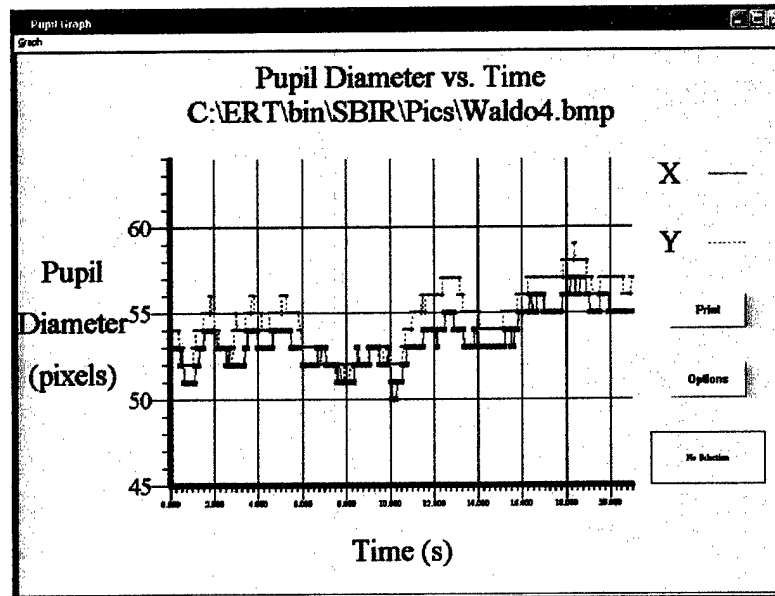
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